the CH_3 group in ethyl alcohol amounts to only about 6 cycles per second and requires for its resolution a homogeneity of the external field over the sample region to within about one milligauss. In a typical field of 7000 gauss this represents a resolution of one part in 7 millions which can be achieved with considerable care.

It is tempting, however, still to increase the resolution at least tenfold in order to observe further interesting details. While it would seem very difficult to obtain a field of sufficient homogeneity, it is possible to reach this goal in a rather simple way, i.e., by providing a motion of the substance within the sample under investigation.

The mechanism can be qualitatively understood by assuming that the external field varies over the sample by an amount of the order ΔH and that a given molecule participates in the macroscopic motion of the substance in a manner such that, during each time interval of the order t, it is once exposed to the range of variation ΔH of the magnetic field. The more rapid the motion, i.e., the shorter the interval t, the more a nucleus in the molecule reacts as if it were exposed all the time to the average value of the field. It can be shown that the effect will start to become appreciable if

$$t\cong 2\pi/(\gamma\Delta H), \tag{1}$$

where γ is the gyromagnetic ratio of the nucleus under consideration. As an example we consider protons in an external field which varies over the sample by the amount $\Delta H\cong 2\times 10^{-3}$ gauss. To obtain an effective averaging of this field, one has to demand, according to Eq. (1), that the time t be less than about $\frac{1}{10}$ sec. In a sample with linear dimensions of $\frac{1}{2}$ cm this requires a speed somewhat higher than 10 cm/sec, which is certainly well within the realm of mechanical possibilities.

It must be noted that formula (1) implies that every molecule in the substance experiences the *full* range of variation ΔH during the time interval t. Generally, however, the averaging process will take place for each molecule only over those regions of the sample through which it is carried in the course of its motion. As a result one will observe a *partial* narrowing of the line which, however, can be very appreciable under suitable circumstances.

A more quantitative treatment of the effect is obtained from the phenomenological equations of nuclear induction.[2] Assuming, for example, that the motion within the substance has the effect of exposing a given molecule, after a mean time θ, to a randomly different field within the sample, one obtains for short θ a reduction of the field inhomogeneity to an "effective value"

$$(\Delta H)_{\text{eff}}=\gamma\langle(\Delta H)^2\rangle_{\text{Av}}\theta, \tag{2}$$

where $\langle(\Delta H)^2\rangle_{\text{Av}}$ is the mean square deviation of the field in the sample from its average value. Irrespective of the manner in which the external field varies over the sample, one obtains in this case a "Lorentzian" line with an "effective" transverse relaxation time

$$(T_2)_{\text{eff}}=1/[1/T_2+\gamma(\Delta H)_{\text{eff}}], \tag{3}$$

where T_2 is the transverse relaxation time due to natural broadening.

[1] This structure is distinguished from the one reported earlier by Arnold, Dharmatti, and Packard [J. Chem. Phys. **19**, 507 (1951)] where the OH, CH_2, and CH_3 groups in ethyl alcohol were shown to lead to separate resonances. Higher resolution reveals that each of these resonances consists of a number of closely spaced lines. These more recent findings will soon be published.

[2] F. Bloch, Phys. Rev. **70**, 460 (1946).

A Line-Narrowing Experiment

W. A. Anderson and J. T. Arnold
Stanford University, Stanford, California

(Received February 19, 1954)

THE possibility of line narrowing by macroscopic motion of the material within a sample, described in the foregoing letter, has been experimentally established. A nuclear induction apparatus consisting of a 7000-gauss permanent magnet and the associated radio-frequency components was used. The magnet was shimmed to give a homogeneity within about 10^{-3} gauss over a spherical sample of $\frac{3}{16}$-inch diameter.

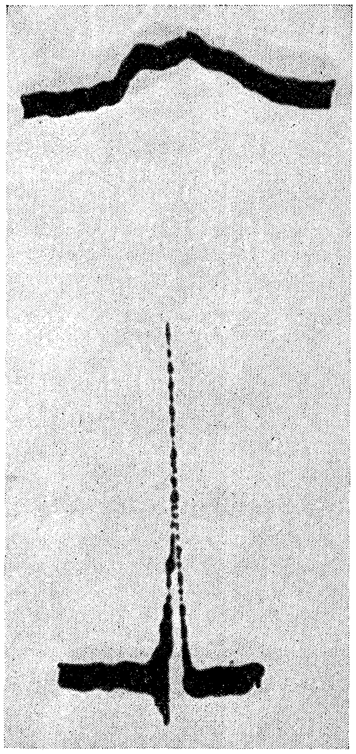

Fig. 1. Line narrowing by rotation. The top figure is a photograph of a proton resonance from distilled water displayed on the cathode-ray screen. The beam was swept from right to left in about 30 seconds. A measure of the external field inhomogeneity is given by the width at half-maximum and was found to be 1.7×10^{-3} gauss. The bottom figure was obtained by rotating the spherical sample at a rate of about 25 times per second, but under otherwise identical conditions. The variation of the field between the two ends of this trace was determined by calibration to be 3.5×10^{-3} gauss, yielding for the width at half-maximum about 10^{-4} gauss. This reduction in half-width is accompanied by an increase of the height by a factor of about 7.

A simple and effective way to induce a macroscopic motion was found to be a rotation of the entire sample about an axis (y), coincident with the axis of the receiver coil. This method achieves a partial narrowing in the sense that it effects an averaging over the field around coaxial circles in the plane normal to this axis. It has been possible in this manner to narrow the line appreciably and thereby increase its height with rotational speeds in excess of about 10 cycles per second. This is in agreement with the order of magnitude of the time t, referred to in the previous letter. The samples were enclosed in a shaft extending into the receiver coil. This shaft was driven by a small air turbine located above the head.

The figure shows oscilloscope traces of proton resonance lines in distilled water with and without rotation of the sample. It is seen that the rotation of the sample results in a reduction of the half-width by a factor of about 17 and an increase of the maximum by a factor of 7. The fact that the areas under the two curves do not seem to agree is possibly due to partial saturation in the case of the narrower line.

Since simple rotation averages only along coaxial circles, the best over-all homogeneity for the stationary samples will not necessarily represent the optimum field configuration under rotation. For example, in the best over-all field there may be a comparatively strong variation in the y direction over which no averaging takes place in the present arrangement. Thus the relatively broad line in the figure does not represent the best resolution to be obtained without rotation. In fact, our magnet is capable of homogeneities over the sample within as little as $\frac{1}{2}$ milligauss.

With the enhanced resolution which has already been realized, we have investigated some interesting new features of the proton resonances in ethyl alcohol.[1,2] The results of these and further studies will soon be published, together with a more detailed description of the apparatus.

We wish to express our gratitude to Professor Bloch for the most helpful discussions concerning this work.

---

[1] Arnold, Dharmatti, and Packard, J. Chem. Phys. **19**, 507 (1951).
[2] J. T. Arnold and M. E. Packard, J. Chem. Phys. **19**, 1608 (1951).

Nuclear Spin of Am^{243} and Isotope Shift in the Americium Spectrum[*]

John G. Conway and Ralph D. McLaughlin
Radiation Laboratory, University of California, Berkeley, California

(Received February 23, 1954)

Recent advances in nuclear chemistry have made it possible to obtain relatively large amounts of Am^{243}. The quantities available are of such size as to make the determination of nuclear spin feasible by spectroscopic methods. Two 30-microgram samples of americium were recently obtained for this purpose. One contained roughly 10 percent Am^{243} and 90 percent Am^{241}, and the other contained roughly 80 percent Am^{243} and 20 percent Am^{241}.

The samples, which were received in an aqueous solution, were evaporated to dryness upon graphite electrodes which were 0.25 inch in diameter. The sample excitation was performed by a direct current arc which was regulated to pass 15 amperes of current. The spectrum was recorded in the second and third orders of a 21-foot, 30 000 line per inch grating in a Paschen-Runge mount. An iron spectrum and an Am^{241} spectrum were photographed for comparison.

TABLE I. Isotope shifts in the americium spectrum, and wavelengths of the first component in the flag pattern of Am^{243}.

λ_{243}(A)	$\Delta\lambda_{243-241}$(A)
2815.17	+0.022
2888.46	−0.017
2909.72	+0.014
2911.06	−0.009
2938.96	+0.069
2957.13[a]	−0.009
2958.29	+0.007
2969.21	+0.014
2993.38	+0.014
3027.91	+0.021
3161.19[a]	−0.025
3204.05	+0.020
3225.27	+0.040
3257.93	−0.007
3258.62	−0.080
3282.48[a]	−0.024
3262.67[a]	−0.020
3451.99	+0.014
3473.16	+0.014
3496.48	+0.007
3926.07	+0.013
4372.35	+0.058
4441.43[a]	+0.026
4509.16	+0.032
4680.84[a]	+0.012
4699.46	+0.031
4786.64	+0.071
4871.93	+0.032

[a] Lines in which the first component is on the higher wavelength side of the pattern.

Fred and Tomkins[1] have reported the hyperfine structure of Am^{241} to be a flag pattern of six components with a spin of 5/2. No differences were observed in the hyperfine structure of Am^{243} and Am^{241}. Both structures form a flag pattern of six lines. Since Am^{243} shows six hyperfine components, it must have a nuclear spin of 5/2. There is no reason to doubt the validity of the assumption that J is greater than I. Within 2 percent error the patterns of Am^{243} and Am^{241} have the same over-all width. This indicates that the nuclear magnetic moment must be equal in the two isotopes.

The isotope shift between Am^{243} and Am^{241} was also observed. Table I contains the wavelengths of the first component of the pattern of the hyperfine lines for Am^{243} and the shift between Am^{243} and Am^{241} of that component.

We wish to thank Dr. E. K. Hulet and Dr. S. G. Thompson for providing us with the samples of americium and Professor F. A. Jenkins of the Physics Department, University of California, for the use of the spectrograph.

---

[*] This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. Fred and F. S. Tomkins, Phys. Rev. **89**, 318 (1953).

Angular Distribution of Photoelectrons from Gamma Radiation of 0.4 and 1.3 Mev

Arne Hedgran and Sölve Hultberg
Nobel Institute of Physics, Stockholm, Sweden

(Received March 2, 1954)

The knowledge of the angular distribution of photoelectrons and its energy dependence is of value especially for beta-spectrometric comparisons of gamma-ray intensities. At a gamma-ray energy of 2.6 Mev the angular distribution has been studied by Latyshev,[1] and the present paper gives the results of an experiment with the Au^{198} 0.41-Mev and the Co^{60} 1.33-Mev gamma rays.

The investigation was carried out by using a large double-focusing spectrometer ($\rho=50$ cm) and with the setup shown in Fig. 1 A.

The photoelectric converter was placed at the usual source position of the spectrometer, and the gamma source was fixed to an arm that could be moved horizontally around an axis through the converter center. The setup was constructed with a minimum of material around source and converter. The photoelectron peaks were recorded with the spectrometer for different angles θ between arm and spectrometer axis. The height of the peak for an angle θ is simply proportional to the photo cross section for the corresponding unit solid angle. At larger θ the converter subtends a smaller solid angle to the source, but this effect is canceled by the fact that the gamma rays have to traverse more material in the converter. A correction has, however, to be applied because of the finite angular resolution which results from (1) geometry (the combined effect of finite spectrometer aperture, source size, and the finite solid angle under which the converter is irradiated) and (2) electron scattering in the converter.

For the Co^{60} experiment a source of 500 mC with cylindrical shape (height and diameter 4 mm) was used. The converter was a circular 7 mg/cm^2 lead foil ($\Phi=10$ mm), source-converter distance was 45 mm, and the circular entrance aperture ($\Phi=50$ mm) was at a distance of 300 mm from the converter. The use of two G-M counters in coincidence and elaborate shielding reduced the background from the strong source to a satisfactory level.

Figure 1 B shows the heights of photoelectron peaks with their estimated uncertainties for different θ. The angular resolution curve was calculated to be approximately a Gaussian with a full half-width of 21°, the contributions from geometry and scattering being about equal. By an unfolding procedure the experimental curve was corrected for angular resolution, giving as result the dotted curve, which should represent the true photoelectron distribution.

For the Au^{198} experiment a sufficiently thin lead converter was not available, so a gold foil (1.7 mg/cm^2) was used as converter. A 400-mC source (diameter 5 mm, height 1 mm) enclosed in aluminum was used, and the geometry was similar to that in the previous experiment. Figure 1 C shows the observed photoline peak heights plotted against θ (full line) and the corrected curve

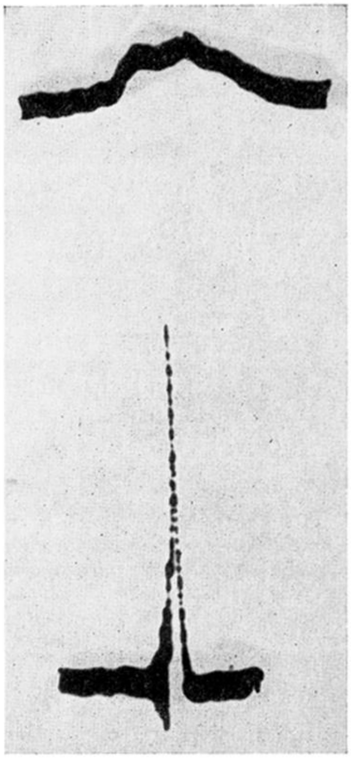

FIG. 1. Line narrowing by rotation. The top figure is a photograph of a proton resonance from distilled water displayed on the cathode-ray screen. The beam was swept from right to left in about 30 seconds. A measure of the external field inhomogeneity is given by the width at half-maximum and was found to be 1.7×10^{-3} gauss. The bottom figure was obtained by rotating the spherical sample at a rate of about 25 times per second, but under otherwise identical conditions. The variation of the field between the two ends of this trace was determined by calibration to be 3.5×10^{-3} gauss, yielding for the width at half-maximum about 10^{-4} gauss. This reduction in half-width is accompanied by an increase of the height by a factor of about 7.